SHORT LATENCY EVOKED POTENTIALS AND INTRA-INDIVIDUAL VARIABILITY IN CHILDREN

by

Janiece Marie Lord-Maes

A Dissertation Proposal Submitted to the Faculty of the

DEPARTMENT OF EDUCATIONAL PSYCHOLOGY

In Partial Fulfillment of the Requirements
For the Degree of

DOCTOR OF PHILOSOPHY

In the Graduate College

THE UNIVERSITY OF ARIZONA

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GRADUATE COLLEGE

As members of the Final Examination Committee, we certify that we have read

the dissertation prepared by Janice Lord-Maes

entitled Short Latency Evoked Potentials and Intra-individual Variability in Children

and recommend that it be accepted as fulfilling the dissertation requirement

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DEDICATION

This project is dedicated to David, Davina and Zachary, for their patience, endurance and love.

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TABLE OF CONTENTS

TABLES

ILLUSTRATIONS

ABSTRACT

Individual differences in learning with a focus on neuropsychological anomalies underlying learning strategies, have been receiving attention in recent years. As a result, interest has increased in quantifying and analyzing cognitive behavior more directly. One of the tools that measures brain activity directly is the evoked potential (EP).

This study investigated the EP recorded from the brainstem region, often referred to as brainstem auditory evoked response (BAER). The importance of BAERs in detecting pathology in the brainstem has been well documented. BAERs have also been advocated as an important tool in the electrophysiological assessment of children's brainstem function relative to learning disorders.

BAER latencies were recorded, therefore, from a small group of average children and studied in relation to the BAER stability over time. Intra-individual differences were compared to between-subject differences.

So little BAER research has been performed with children that more studies are needed just to clarify normal variability of BAER parameters. The present investigation studied intra-individual differences in the stability of BAER latencies over time in young subjects with normal hearing, for comparing with and contrasting to previous results from a study using an adult sample.

BAER latencies were recorded for left, right, and binaural ear presentations. A coefficient of stability (CS) was calculated for each peak, for each ear over time. ANOVA results showed significance for peak and peak X ear interaction. Several BAER details were examined within subjects that may not be revealed in studies between subjects. Profiles for intra-aural differences over time showed individual differences in the stability of the BAER. Although there appeared to be a trend toward inter-ear differences these differences did not reach significance.

The profiles indicated considerable intra-aural pattern replicability, inter-ear differences and a trend toward increase in stability over time. The results supported a need for future research on laterality studies, more age specific normative data and correlational studies in relation to individual cognitive differences.

INTRODUCTION

Psychological constructs, such as intelligence, cognitive strategies, and information processing skills have been used by social scientists to examine the nature and extent of variance in children's learning (Spearman, 1904; Cattel, 1971; Vernon, 1961; Sternberg, 1982; Anderson, 1978). Explanations of individual differences in learning currently focus on rapidly accumulating evidence in support of neuropsychologic and neurologic anomalies underlying various learning strategies (Molfese & Molfese, 1985; Obrzut, Morris, Wilson, Lord & Caraveo, 1987; Rourke, 1985; Satz & Morris, 1981). The interest in neuropsychology reflects the assumption that there are mechanisms in the brain which can be investigated to understand cognitive processes. Therefore, methods which purport to measure these processes are believed to provide relevant information regarding variance among individual learning strategies. The overall focus of this paper is to investigate a more direct measure of cerebral activity: evoked potentials (EP). Until recently cognitive processes in the educational field have been measured by use of psychoeducational test batteries (Anastassi, 1982). Although these measures have provided quantitatively useful results with regard to the outcome of learning, they have not been able to explain adequately the mechanisms underlying learning.

Recent years have witnessed an increasing interest in quantifying and analyzing cerebral output and behavior in a more direct fashion. Therefore this study intended to measure EPs collected from the auditory nuclei in the brainstem. This measurement has clearly demonstrated its usefulness as an objective measure of hearing, of auditory processing, and of structural brain damage in children (Sohmer & Student, 1978; Hall, Speilman, & Gennarelli, 1982; Jacobson & Morehouse, 1984). Specifically, this study intended to investigate intra-individual variability of brainstem evoked response latencies in children over time.

Neuropsychological alterations have been considered as factors underlying individual differences in learning since the beginning of the 19th Century (Sutton, Whitton, Topa, & Moldofsky, 1986). Since that time, various approaches have been used to investigate differences relative to the integrity and complexity of the brain. Neurochemical studies for example, suggest that individual differences in cognitive functioning may be accounted for, in part, by differences in dopamine metabolism (Conners, 1976; Wender, 1976), and psychopharmocological studies indicate that "drugs can be used to improve selected intellectual functions of the brain" (Dimond, 1976, p. 368; Spraque & Sleator, 1976).

Genetic and maturational influences, as well as cerebral dominance and perceptual factors (Knights & Bakker, 1976; Sternberg, 1982; Geschwind & Galaburda, 1986; Tallal, 1976) have been investigated for their influence on learning-related brain activity. Results from these studies have increased interest in biology to help explan variability in cognitive skills (Pizzamiglio, 1976; Heilman & Valenstein, 1985; Gazzaniga, 1970; Geschwind & Galaburda, 1986). Several views on cerebral organization have been presented. For example, Luria (1973) viewed the brain in terms of three phases (arousal, decoding/encoding, and interpretation and execution) with all phases being essential to the final generated behavior or cognitive processes that support the behavior. Geschwind (1965), Geschwind and Levitsky (1968), and Gazzaniga and Sperry (1967) have explained cerebral organization in terms of asymmetries in hemispheric processing.

Whether the organization of the brain is viewed in terms of right and left hemispheres or according to a caudo-rostral orientation describing functional sections, there is broad agreement that cerebral functions involve electrical activity generated within the brain. "A large segment of attempts to gain an appreciation for the functional organization of (sensory) cortex is based on the study of responses expressed as electrical activity and engendered under specific, operationally defined stimulus conditions" (Goff, Allison, & Vaughan, 1978, p.4). One such response is a discrete time-locked electrical activity that can be noninvasively measured from electrodes placed on the scalp. Electrical responses from cortical as well as subcortical activity generated in the brainstem can be recorded (Jewett, Romano, & Williston, 1970).

Traditionally, clinical observation of electroencephalography (EEG) has been the major technique for investigating cerebral electrical activities. This technique has been sharply criticized, however, for producing less than adequate qualitative interpretations (Harmony, 1984) and unwieldly records (Lundborg, 1981; Reneau & Hnatiow, 1975). As a result, the need for new quantitative measures became widely recognized.

Technological advances made possible the extraction of small discrete electrical brain potentials reflective of specific cognitive, perceptual and sensory brain functions (Callaway Tueting, & Koslow, 1978; Moore, 1982). Computer analysis of the output of scalp placed electrodes has become a widely accepted procedure to analyze variability in brain electrical potentials and has been used to describe individual differences in response to a variety of sensory input. Technological developments are being pursued to facilitate identification of more precise measures to define the parameters of the components of cerebral electrical activity (Picton, Hillyard, Krausz & Galambos, 1974; Callaway, Tueting, & Koslow, 1977; Donchin & Smith, 1970; Capute, Niedermeyer & Richardson, 1968; Lauter & Loomis, 1986; Sand, 1986).

The past decade has seen major developments in electrophysiologic assessment of central nervous system functions. Auditory evoked responses, in particular, have had an impact on the identification and differentiation of peripheral and CNS pathology. Before reviewing the research, this chapter presents the major principles of evoked potentials, specifically brainstem auditory evoked potentials.

Evoked Potential

Electrical potentials form a series of waves as a result of activation of a great number of neurons from various brain regions. The potentials are referred to in a variety of ways such as averaged evoked potential (AEP), and averaged evoked response (AER). They may be named more specifically according to the level of the neurons presumably most important for their generation (cortical evoked response, brainstem evoked response) or in terms of the sensory modality used: visual evoked response (VEP), somatosensory evoked response (SEP), or auditory evoked response (AER).

The terms "potential" and "response" have been used interchangeably. In this paper the acronym AER will be used to refer collectively to all averaged evoked responses generated from any of the sensory modalities: VEP, SEP, or BAER, except when it is used in a quotation and means otherwise.

Historically AERs have been investigated for their value in diagnosing only medical/physical anomalies. For example, cortical somatosensory evoked responses were used in the early 1960s to document abnormalities associated with multiple sclerosis; and pattern-reversal checkerboards were found to evoke abnormal VEP patterns in patients with optic neuritis (Kjaer, 1986). Jewett, Romano, and Williston (1970) were among the first to pioneer the recording of volume-conducted auditory evoked potentials, and explored variables affecting the various brainstem responses. These and other studies using BAERs were of interest to clinicians and researchers involved in the scientific study of auditory disorders.

Evoked potentials have not escaped criticism. Clinical electrophysiologists and others, accustomed to analyzing data from ink records or photographs, have found it difficult to see a direct link between cerebral activity and mathematically derived measures. Work by Jewett et al. (1970), Jewett and Williston (1971), Moore (1983), and Despland & Galambos (1980) however, has supported the value of averaged evoked potentials as a clinically useful diagnostic tool.

Applications of evoked potentials currently range from neuropathology in the elderly through recognition of other brain dysfunction to cognitive impairment in children. Research utilizing EP responses may provide alternate avenues toward understanding cerebral organization and/or behavioral correlates of cognitive function. Measures obtained from EP recordings may assist in the development of standard methodology and a better diagnostic taxonomy in learning disabilities. John et al. (1988) suggested the use of neurometrics, as a method to quantify electrophysiology for diagnosis of cognitive dysfunction.

The significance of evoked potentials for clinicians, scientists in opthalmology, otolaryngology, pediatrics, neurology, neuropsychology, electroencephalography, neurophysiology and special education has been described by Myklebust (1973). John (1977) and Thatcher and John (1977) have discussed how electrophysiological data elucidate brain activity and provide neuroscience with a more direct approach to brain-behavior relationships. In addition, various aspects of the clinical value of AERs are reviewed in the literature (Reneau & Hnatiow, 1975; Morucutti & Rizzo, 1985; Courjon, Mauquiere, & Revol, 1982) and will not be repeated here. This paper is designed to address questions concerning variability in individual responses elicited from the brainstem. The brainstem auditory evoked potential (BAER) is but one aspect of the entire auditory system, yet it contributes a vital part to the understanding of cognitive neurophysiological development.

Brainstem Auditory Evoked Response: BAER

BAERs are elicited by an acoustic stimulus; the neuronal activity is believed to follow the anatomy of the auditory afferent pathways. BAERs are typically recorded as the difference between voltage obtained from an electrode placed at the top of the head (vertex) and one placed on the earlobe or mastoid process. "AERs are a sequence of neuro-electric voltage changes, a series of positive and negative waves reflecting activation of the eighth cranial nerve and auditory regions of the brainstem and cortex by sound stimuli" (Hall, et al., 1982, p. 225). The response of the brainstem portion of this afferent pathway comprises a series of 5-7 vertex-positive voltage peaks occurring within the first 8-10 msec following presentation of an auditory stimulus, such as clicks (see Appendix).

The first five peaks are most frequently of interest. Measurement parameters include the latency of each peak or time between the onset of the stimulus and the occurrence of that peak in the BAER. Wave components are numbered I, II, III, IV, V, according to a system of numbering proposed by Jewett et al. (1970) in their pioneer paper. Jewett and Williston (1971) suggest that wave I is generated by activity in the eighth cranial nerve, and waves II thru IV reflect subcortical function of the auditory system. Wave V is purported to be the most robust, with a latency of 5 to 6 msec and an amplitude of 0.5 uV (Hall, et al., 1982). This information serves as a general basis for clinical norms.

Research conducted to date has provided insight into some of the factors influencing the configuration of brainstem evoked responses. Stimulus parameters, such as stimulus repetition rate (Starr & Anchor, 1975; Hecox & Galambos, 1974; Jewett & Williston, 1971), and stimulus frequency (Eggermont & Don, 1980; Don & Allen & Starr,

(1977) have been shown to have an effect on BAER responses. Individual differences in BAER have been studied with reference to subject characteristics such as age (Hecox & Galambos, 1974; Salamy, McKean, Pettett, & Mendelson, 1978), gender (Beagley & Sheldrake, 1978; Michalewski, Thompson, Patterson, Bowman & Litzelman, 1980), and body temperature (Stockard, Sharbrough & Tinker, 1978). Results from studies reviewed by Glattke (1983), indicate that BAER latencies are quite stable in normally hearing populations. Waves III and V in humans are found to be the most robust across all variables.

BAER variability has been analyzed with respect to a number of comparisons, such as: group designs with no repeated measures; different subjects under different laboratory settings; experimental groups compared to control; and variability among different experimental groups. The emphasis in the literature has been on between-group differences but little attention given to intra-subject variability across time. Some data have been reported concerning normal variability in single sessions (Edwards, Buchwald, Tanguay, & Schwafel, 1982), and a few studies have focused on normal variability within groups (Rosenhammer, Lindstrom & Lundburg, 1978; Chiappa, Gladstone & Young, 1979). Until recently, no data on within-subject BAER variability over time were available.

Sohmer and Student (1978) posited that subtle differences in children's BAERs exist and recommended more sophisticated analysis to detect these differences. Weber and Omenn (1977) stated that when their dependent variable was defined in terms of intra-subject variability several subjects showed significant differences. Further investigation focusing on single subjects studied over time is needed for a more complete understanding of the degree to which the potentials reflect normal individual differences.

Lauter and Loomis (1986) utilized a repeated measures design for BAER testing in adults, and demonstrated significant within-subject peak and ear differences in BAERs. They discussed the clinical importance of records regarding within-subject variability and pointed out that "little is known regarding the changes in AER responses in one subject over time " (p. 70).

Interpretation of information collected on BAERs in applications such as developmental disabilities depends on the analysis of patterns in relation to some established norm of variability (Lauter & Loomis, 1986). Hecox, Cone, and Blaw (1981) reported on the benefit of BAER in detection of intercranial pathology and emphasized the need for age specific norms (p.839). In the absence of such normative data, non-pathological individual peculiarities may erroneously be mistaken for pathological impairments (Fria, 1980). It is possible that quantitative documentation of intra-individual differences in the BAER over time could help define parameters of normal variability.

Purpose

The purpose of this research was to: a) collect and describe brainstem auditory evoked response latencies in young subjects over repeated sessions; b) to compare the stability of the BAER responses within-subject to the stability of BAER responses between-subject; and c) to explore the possibility that BAERs from young subjects may reveal characteristics of central auditory function not available in data based on group averages.

Eight children were tested in 8 separate sessions. Scalp electrodes were utilized to obtain brainstem evoked responses to three stimulus presentation conditions: left monaural, right monaural, and binaural. Measures of peak latency were obtained from waveforms stored on disk for each of the 3 modes of ear presentations.

Based on the results, subsequent research could be pursued using BAER as a tool for studying the physiological correlates of differences in learning. Such research could lead to formulation of an effective objective means to identify high-risk children during infancy or children at risk for academic failure.

LITERATURE REVIEW

There has been an increased recognition that neuropspychological knowledge may apply to the understanding of childhood learning disorders (Gaddes, 1984; Rourke, 1985; Fisk & Rourke, 1983; Obrzut & Hynd, 1984). Frequently a learning disorder in children is associated with some auditory dysfunction. A child with average to above average intelligence may experience hearing problems and/or difficulties interpreting the meaning of auditory input. The disorder may involve central nervous system activity associated with the auditory sensory pathway.

The brainstem includes several auditory nuclei, and the electrical responses from these nuclei have been of concern recently in neuropsychological research. Brainstem electrical responses have been analyzed relative to audiological assessment (Despland & Galambos, 1980) differentiating select learning groups (Obrzut et al., 1987) as support in medical diagnoses (Chiappa, Harrison, Brooks, & Young, 1980) and verification of cerebral dysfunction (Davis, Aminoff & Berg, 1985). Based on this information and that introduced earlier, this chapter reviews the literature on Brainstem Auditory Evoked Responses (BAER) with children and in particular children with auditory learning disorders. The chapter will be organized in five sections, with section I providing a brief overview of the association between auditory processing and school learning. Section II addresses developmental information revealed in BAER studies with infants. Review of the literature concerning the variability among BAER parameters in children with learning disorders (especially auditory learning disorders) will be presented in section III. Section IV deals with methodology used in BAER research with children. A final section, V, will concern the value of investigating the parameters of normal individual differences in BAER latency measures.

Auditory Processing and School Learning

The importance of the auditory channel in the development of higher cognitive skills has been established (Betts, 1934; Golden & Steiner, 1969; Rosenberg, 1966; Semel & Wiig, 1975). Semel (1976) points out that effective auditory processing is critical in a learning environment and emphasizes the importance of auditory processing in the development of higher cortical skills such as reading, cognition, and communication.

Simmons (1975) postulated that without causing deafness, a lesion in the auditory nuclei of the brainstem could interfere with a child's ability to discriminate various features of speech, thus disturbing his or her language development. When a continual hearing problem or intermittent auditory difficulties are suspected in a child, an audiological evaluation is required. The results are interpreted in relation to the subject's adaptation to the environment relative to the hearing deficit. In some cases a hearing loss may not be detected. For example, children with otitis media may not evidence a hearing loss as the disease is recurrent; however, these children often show deficits in language development and subsequent learning problems (Reichman, Healey & Healey, 1983). A high frequency hearing loss is generally associated with loss of consonant recognition. Often, deficits that are less severe can be unnoticed relative to expressive language, yet may be severely debilitating relative to academic learning in young children. Such a child may be falsely accused of inattention or uncooperative behavior. The energy level required to maintain the appropriate level of auditory attention may be too demanding for the child and cause decreased attention.

The literature is replete with evidence supporting the complicated nature of auditory perceptual problems.

Auditory channel deficits can range in severity. An undiagnosed receptive language problem may be treated as deafness or a less severe loss may cause a child frustration in daily conversational situations (Alberti, Hyde, Corbin & Abramovich, 1983). An undiagnosed loss of the auditory message leads to misdiagnosis and complicates the chances for successful remediation of learning (Reeves, 1980).

In addition, auditory perceptual problems are often precursors to academic difficulties, such as an inability to comprehend or follow directions, distractibility, or a tendency to produce an irrelevant response. Some of the more frequently demonstrated behaviors resulting from auditory perceptual difficulties involve deficits in discrimination of sound, sound blending, sequencing and temporal order, and significant differences between memory for repeating digits backwards when compared to a more intact ability to repeat them forward (Kramer, Schell, & Rubinson, 1983; Semel & Wiig, 1981; Groff, 1975). At times, children with auditory processing problems may display hyperactive or hypoactive behavior which could lead to an emotional lability of various degrees (Reeves, 1980).

Details of auditory mechanisms and physiology are covered explicitly in the literature; here only the aspects relevant to the auditory pathway of the brainstem will be emphasized. Malfunctions within the auditory channel can occur at the various anatomical levels from the outer ear to the cortex. The peripheral ear or pinna, outer ear canal, and middle ear may be the cause of hearing difficulties and may degrade the initial input to the auditory system (Glattke, 1983). Available evidence indicates, however, that the conduction of electrical activity in the brainstem is not significantly affected by peripheral hearing disorders affecting these structures (Eggermont & Don, 1980; Rosenhammer, Lindstrom & Lundborg, 1978). The inner ear is the part of the auditory system that converts mechanical activity into nerve excitation (Glattke, 1983), and influences the electrical activity in the brainstem. Impairment to the brainstem is believed to result in various auditory processing disorders.

A relatively recent approach designed to identify auditory processing anomalies has been the collection and computer analysis of electrical potentials evoked from the brainstem by an auditory stimulus. The degree to which brainstem auditory evoked potentials are able to predict auditory integrity is well documented in the literature (Despland & Galalmbos, 1980; Jacobson & Morehouse, 1984; Jacobson, Morehouse, Johnson, 1982). "It is also evident that ABR can play a key role in the accurate identification of mild to profound hearing loss" (Jacobson & Morehouse, ibid, p. 252). Furthermore, research has demonstrated the importance of BAERs in the detection of pathology in the brainstem and the potentially adverse effects these anomalies may have on auditory development (Alberti et al., 1983). Early detection becomes especially salient when consideration is given to the fact that before language expression the young individual has already experienced a year or more of language reception involving complex intellectual events.

Developmental Aspects and BAER with Infants

Research utilizing the BAER technique with infants has demonstrated several clinically useful facts. Studies have demonstrated BAERs as a valid measure in the diagnosis of neurologic disease (Starr & Hamilton, 1976; Stockard & Sharbrough, 1980), and as an objective audiological measure in hard to test infants (Stockard & Sharbrough, 1980; Despland & Galambos, 1980; Makotoff, Schulmann-Galambos & Galambos, 1977). Other studies have demonstrated differences in BAER latencies from a developmental perspective with premature and term infants (Starr, Amlie, Martin & Sanders, 1977; Despland & Galambos, 1980; Shulman-Galambos, & Galambos, 1975); results from these studies suggest latency decreases with age up to approximately 18 mo. at which time latencies become similar to that of an adult.

Jewett et al., (1970) suggested that the greatest evidence of wave peak replicability is found with peaks III and V. Infant studies have demonstrated the clinical significance of these robust wave peaks in that the absence of either or both peaks has been associated with various insults, i.e., asphyxia (Hecox & Cone, 1981), infections (Finitzo-Hieber, Simhadri & Hieber, 1981), and myelination disorders (Hecox & Cone, 1981). Correlational data relating specific antecedent conditions to the absence of any particular wave peak, or associating an abnormal BAER component with a particular pathology, await future research. In general, abnormal BAER components are attributed to a pervasive cerebral dysfunction (Cevette, 1984; Sohmer & Student, 1978; Davis, Aminoff & Berg, 1985).

Early evaluation for auditory dysfunction in infants has revealed the transitory nature of the BAER in follow-up tests. Studies (Jacobson, Morehouse, 1984; Stein, Oxdamer, Kraus & Patton, 1983) suggested the need for longitudinal follow-up testing to clarify the discrepancy between the high incidence of abnormal BAERs in infants seen in the intensive care units and those found at follow-up. The transitory nature of BAER abnormalities in this age group necessitates follow-up testing and additional examinations before inferences are made about neurodevelopmental disorders (Stein, et.al., 1983). These researchers suggested that more attention be given to individual differences at the initial evaluation, thereby providing more detail for prognosis. They stated that the "difficulty...can be reduced if screening protocol is expanded to include threshold and latency measures in each infant who fails initial screening" (p. 452). The additional individualized, definitive examination should result in improved treatment, accuracy of information, and better separation between conductive and neurologic impairment.

Other advantages to recognizing details obtainable in BAER parameters can be found in the interpretation of results. For example, drastic differences were found in the results of two studies which estimated "failure rate" with infants. Failure rate is defined here to mean absence of wave peak V (Marshall, Reichert, Kerley, & Davis, 1980; Roberts, Davis, Phon, Reichert, Sturtevant, & Marshall, 1982). Marshall et al. (1980) and Roberts et al. (1982) found discrepant failure rates of 21% and 59% respectively in similar studies testing BAER components with infants assigned to an intensive care unit. Roberts et al. stated that wave V was observable in only half of their term population due to immaturity. Robert's sample of infants who failed ranged in age from 28 to 36 weeks. Current evidence suggests that peak V is observable and measurable at age 40 weeks at 30 dB SL (Galambos, Hicks & Wilson, 1984), and that BAERs are not fully developed in infants prior to 32nd week of post gestational age (Jacobson & Morehouse, 1984). If a normal variability base for infants or children was clearly articulated such discrepancies between studies, as well as the misleading interpretation of infant failure rates, may be avoided. It is also possible that data specific to normal variability across age groups could provide additional prognostic value.

Problems with adequate identification of high risk infants, and with securing appropriate follow-ups and provisions for early intervention contribute to adverse effects in subsequent language acquisition of children (Alberti et. al., 1983). School age children with a profile indicative of auditory processing difficulties often experience academic problems and are categorized as learning disabled. "Recent literature suggests that some learning disabled children demonstrate neurological dysfunction associated with brainstem level auditory functioning" (Tait, Roush, & Johns, 1983, p. 56).

BAER and Children with Learning Difficulties

Evidence has accumulated rapidly to support the hypothesis that neurological anomolies underlie specific forms of learning disability (LD) (Obrzut, et al., 1986; p. 811; Senf, 1987). Auditory perceptual problems found with LD children are commonly associated with difficulties with psycholinguistic components of language such as phonology, syntax and semantics (Myklebust,1973; Beery, 1969). Disorders of this nature are believed to interfere with a child's ability to decode sensory information and the ability to arrange information systematically. Skills such as these are mandatory for academic success.

Auditory tests to explore subtle auditory processing disorders in children have recently gained interest (Rousch & Tait, 1984). Several experimental paradigms, including dichotic listening, have already been utilized to investigate the central auditory integrity of LD children (Broadbent 1954; Kimura 1961; Obrzut, 1979). In addition the brainstem auditory evoked potential is frequently used as a diagnostic and experimental tool and, as such, has had remarkable impact on clinical medicine. It is recognized for its value as a diagnostic tool in audiological assessment (Howe & Decker, 1980).

The interest in BAER measures and LD children has been generated from earlier studies with adults; e.g. studies investigating peak intervals and latencies in already diagnosed psychopathological and/or neurological disorders (Starr & Anchor, 1975; Chiappa, Harrison, Brooks & Young, 1980). Results showed a significant correlation between the disorders and BAER waveform components (latencies and inter-peak intervals). Similar studies have been conducted with selected groups of children using later (50-300 msec) auditory potentials (Lovrich & Stamm, 1983; Zambelli, Stamm, Maitinsky, and Loiselle, 1977).

The earlier evoked potentials, 1-10 msec, have been advocated as an important tool in the electrophysiological assessment of children's brainstem function (Davis, Aminoff, Bruce & Berg, 1985). Obrzut et al. (1987) reviewed the literature concerning BAERs and learning. they stated that "the application of BAERs to diagnose LD children appears to be promising" (p. 811).

There is a paucity of research utilizing BAERs with children. The studies that are available concern diagnosed pathologies and select group comparisons. The value of such studies is recognized, however, as Sohmer & Student (1978) suggested there is a need for detecting more subtle differences in these electrophysiological measures than what are gained from between group differences.

BAERs with children have demonstrated statistically deviant electrophysiological responses. For example, in a preliminary study, Sohmer and Student (1978) investigated brainstem evoked responses in normal, autistic, minimal-brain-dysfunction and psychomotor retarded children. They found significant differences in latency, transmission time, and wave morphology among the groups. A degree of overlap was found between the groups, and investigators were unable to establish whether the differences indicated difficulties along a continuum or whether the samples represented distinct groups. The investigators suggested the existence of other more subtle differences between response traces and recommended further study to define electrophysiological parameters in more homogeneous and better defined groups. Research efforts to define a range of normal variability for parameters such as peak latencies or latency differences between ears may be a direction for classification schemes between overlapping groups.

Goldman, Sohmer, Godfrey and Manheim (1981) attempted to determine whether BAER measures differed relative to intellectual ability based on WISC test scores. The study compared 77 elementary students (mean age: 11 yrs.) who were defined with respect to their intellectual ability as follows: borderline retardates (R), gifted (G), and normal (N).

Auditory stimuli (clicks) were presented to each subject. The standard brainstem auditory evoked potentials (wave peaks I-V) were recorded, and the amplitudes and latencies for each wave peak measured. The results demonstrated significant amplitude differences between-groups: the "R" group amplitudes were smaller than those of the N group and the N group amplitudes smaller than the G group. Several of the waveforms within the N group were similar to those in the G group, whereas the R group amplitudes remained consistently lower than either of the other groups. No statistically significant differences were found in the latency of respones or brainstem transmission time between groups.

The literature is concerned primarily with between-subjects, or between-group BAER variability; only a few studies have reported data for within-subject variability on subjects. Greenblatt, Bar, Zappula and Hughes (1983) and Lenhardt (1981) have attempted to study intra-aural BAER differences in individuals with identified auditory disorders. In addition to the binaural records presented in previous studies, each of these two studies included reports on intra-aural differences (auditory input to right or left ear) for a single subject.

Lenhardt's (1981) work with an individual experiencing auditory processing disorders showed significant differences in the auditory nuclei from monolateral left and right ear responses. The results showed an absence of wave peak II thru V with right ear stimulation, whereas results from left ear show normal BAER waveform components.

Greenblatt et al., (1983) in a similar study, demonstrated BAER abnormality that was specific to the ear of stimulation. The individual BAER waveform for both left and right contralateral records revealed the absence of wave peak III. Latencies for ipsilateral peaks I and V and for contralateral peak V were within normal limits. Significant differences were demonstrated with respect to inter-aural differences, but data are missing on ear differences in normal individuals. Such data could help in reliable clinical judgements concerning the degree of variability and abnormality.

Piggott and Anderson (1983) demonstrated intra-individual differences in BAER latencies with a small sample of 20 children (7-13yrs). The experimental group (E), was chosen from a psychiatric clinic population based on evidence for an auditory processing difficulty, and compared to a control group (C), some of whom were from the same clinic but free of auditory deficits.

Individual differences between binaural and monaural records for latency measures of wave peak III were found in the E group. Bilateral records of BAER latency demonstrated the expected latency increase in wave peak III for the experimental group. The monaural records for the same BAER parameter demonstrated significant within-subject differences: a longer latency in wave peak III for left ear compared to right ear stimulation.

Intra-aural differences were also found for subjects in the C group for transmission time and amplitude. A significant slowing in transmission time up to wave peak II was found with right ear stimulation; and an increase in the amplitude of wave peak III was found with left ear stimulation. The amplitude for wave peak III was larger for left ear in both the E and C group.

It is important to note, in the context of the current study, that these researchers suggest the existence of normal within-subject variability in brainstem transmission of sound, yet no baseline of normal variability ranges within subject are established. More research in the area of individual differences in BAER waveforms is needed to clarify whether such results are normal physiological differences or whether they represent artifiacts of recording and statistical analysis.

Other studies that have not been able to replicate the relationship between BAER and children's learning difficulty. Tait, Roush and Johns (1983), for example, examined BAERs in a group of 20 boys identified as learning disabled according to the criteria used by the school district. BAERs from this group of students were compared to those of a non-LD group matched for age and without academic difficulty. Results did not reach significance between-groups on BAER latency or transmission-time components. The authors proposed that the sample in former studies must have differed appreciably from theirs. They speculated that students identified as LD in school districts differ from other LD groups and that neurological signs may be present or absent in the school-defined LD. Of interest in this study is the methodology used, in that approximately half the Ss received stimulation presented to the right ear and the other half of the Ss received acoustic clicks presented to the left ear. It is possible that monaural recordings for each ear (right and left), for each subject may have provided valuable information.

Furthermore, examination of the data presented in the study suggests that had the researchers investigated segments of the transmission of the electrical response, as opposed to analyzing only the total transmission time between peaks I-V, additional information may have been revealed. The report indicates similar brainstem transmission time between waves I thru V for both groups. Tables presented in the study display interpeak intervals in milliseconds. The duration between peaks I-III, III-V, and I-V showed 0.06 msec, 0.38 msec and 0.09 msec difference between groups, respectively. When the difference of approximately .4 msec is compared to the .06 msec difference for segment I-III and the .09 msec difference for segment for I-V, the interpeak latency difference for each groups I-III interval, not discussed in the results, may be a significant finding.

A follow-up study by Roush and Tait (1984) investigated intra-aural differences in a language-learning disabled sample of children. Inter-ear differences for absolute latencies of wave peaks I,III, V as well as interpeak duration for I-III, III-V, I-V were investigated. No significant relationship was demonstrated between BAER measures and a diagnosis of language learning difficulties. Results indicate a .02 msec difference between ears (left and right) within group and a .01 and .03 msec interwave difference between groups for right and left ears respectively. Intra-aural latency differences for each of the wave peaks I, III and V were not significantly different for the two groups. Neither numerical data (i.e., ranges for each ear) nor specific statistical information was provided.

Welsh, Welsh, Healy & Cooper (1982) studied a group of 20 students (10 to 13 yrs. of age) chosen from a school for dyslexic children. They found no significant deviations in the BAER latency components when compared to normative data established in their previous work (Welsh, Welsh & Healy, 1980).

In contrast to other studies, Welsh et al. (1982) compared individual deviations to a set norm. Analysis of the individual waveforms showed that 5 out of 20 Ss (20%) deviated significantly from the norm in either latency or amplitude measures. This additional information suggests that details regarding individual differences, not available in group data or between-subjects may enhance research concerning electrophysiological correlates to learning. It seems possible that studying intra-individual differences, such as those suggested by intra-aural BAER differences, could benefit research concerning the LD population where clear empirical conclusions are often difficult to find due to the heterogeneous nature of the disorder itself.

In summary, most researchers suggest a correlation between brainstem potentials and auditory processing and support the BAER as a valid research tool relative to the brainstem electrical responses and language development. Significant differences in the BAER records have been shown between selected groups of children in several studies, and a lack of research on intra-individual BAER variability over time the literature shows that BAER studies are not consistent in prodedures and methodologies. Inconsistent methodology lessens the ability to make generalizations or comparisons among studies.

Methodology in BAER/LD research

The utility of BAERs as a diagnostic tool with LD children has been reduced by conceptual and methodological flaws among studies (Ollo & Squires, 1986; Obrzut et al., 1987; Barenbaum & Harshman, 1980). These methodological differences are often responsible for conflicting results. The diversity of recording techniques, sources of subject referral (clinic or school) and age of subjects, "preclude the synthesis of combined results into a diagnostically useful gestalt" (Ollo & Squires, p.498).

Along with methodological problems found among available BAER studies with children, consideration should also be given to the lack of research utilizing BAERs with LD children. Most research regarding the integrity of brainstem responses with young subjects has focused on group differences. Although useful information has emerged using these approaches, studies analyzing individual differences in children chosen from a normal population have not been done.

Intra-individual Variability

The literature reveals different normal values for peak latencies and amplitudes across different laboratories and more variability of inter-session than of intra-session records. One way to make use of BAER as a more diagnostically specific tool may be to emphasize the parameters of normalcy based on individual differences during testing involving a variety of controlled variables. An approach such as this would allow the examination of specific BAER components in clinical groups using paradigms established in normal subjects similar to that suggested by Ollo & Squires (1986) for later auditory potentials.

A review of the literature shows evidence of variability between experimental groups, and between experimental and control subjects. Some researchers have found evidence of variability in normal subjects and an additional variability in single subjects previously diagnosed with a particular disorder. Questions arise regarding individual variability suggesting the need for further research. The present investigation intends to study intra-individual differences over time in normal young subjects. Research of this type has not been done before except for a study by Lauter and Loomis (1986) on adults. Studies of this general category could provide future details to assist clinical interpretations: (a) in more adequate prognosis of high risk infants (Alberti, Hyde, Riko, Corbin,& Abramovich, 1983); (b) in defining reliable parameters to detect the subtle differences as suggested by Sohmer & Student, (1978); and (c) in providing data that could aid in the confirmation of developmental aspects or aspects of lateralization of perceptual mechanisms related to language development (Molfese & Molfese, 1985). In addition, research in these areas would have a direct influence on research efforts in categorizat

METHODOLOGY

Subjects

Seven children (3 boys and 4 girls) ranging in age from 5.0 to 6.6 years were chosen on a voluntary basis from a local private kindergarten. All subjects met the following selection criteria: average or above average scores on a receptive language test (Peabody Picture Vocabulary Test-Revised, Dunn & Dunn, 1981) and on a test of overall concept formation (Draw-A-Man Test; Harris, 1963), a measure of general intelligence. There were no indications of learning difficulties according to teacher reports, and all volunteers were free of any medication. In addition, the subjects had no record of neurological problems based on parental report. All families of subjects were from middle to upper middle class based on their reported income, and English was the primary language. One male subject, unable to continue the weekly schedule, withdrew during the second week of testing, leaving a final sample of 7.

Parental permission to evaluate was obtained for each child, and parents were requested to provide transportation for their child to the testing site for all scheduled testing sessions. The parental permission form included information about the experiment's non-invasive approach as well as its relevance to establishing possible normative data for future research. An incentive program, $5 per session, was provided. In addition, small novelties such as figurines of cartoon characters, large balloons, small books, and redeemable coupons for a local fast food place were used to maintain the subjects' cooperation and participation.

Examiner: The examiner in this study was a certified school psychologist with a wide range of experience in evaluating children in clinical and academic settings. Her academic background included major course work in neuropsychology, educational psychology and training in the use of the Nicolet CA 2000 by an audiologist employed by the University Medical Center, Department of Otolaryngology. The psychologist also spent many additional hours, on a weekly basis, for a year assisting EEG/EP technologists with evoked potentials in two local hospitals.

Instumentation and Procedures

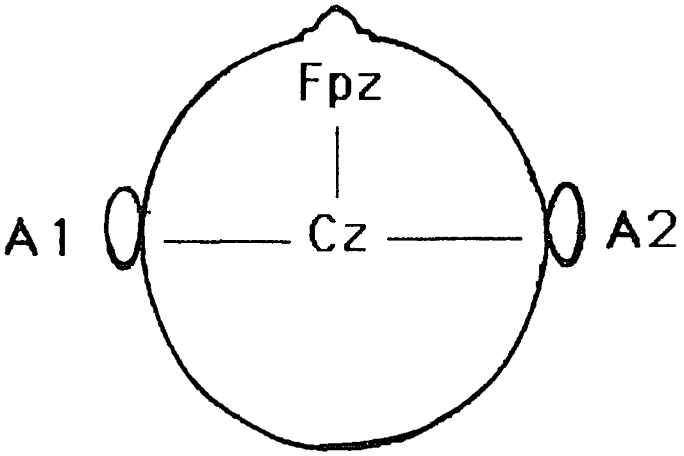
The subjects were tested at the Otolarngology Clinic in the University of Arizona Medical Center. Individual instruction with regard to the requirements expected of them were given to each subject at the beginning of data collection, including a brief orientation to the room containing the equipment, and to the room in which their parents would wait. Every effort was made to assure maximum comfort and co-operation on the part of the subject and parent(s). Each subject was first tested for general ability and language development, using the Peabody Picture Vocabulary Test-Revised (PPVT-R) (Dunn & Dunn, 1981) and the Draw-A-Person Test (DAP) (Harris, 1963). In addition to the objective data obtained from these measures the testing session was used to build rapport and confidence between the subject and examiner.

Brainstem responses were collected from each of the seven subjects using a Nicolet CA 2000 computer. Each subject was tested for brainstem auditory evoked responses, BAERs, in one-hour weekly sessions for eight weeks. All sessions for each subject were scheduled and conducted on the same day and same time of day each week. Testing was conducted in a sound-proofed room in the Otolaryngology Department.

Subjects were screened for normal hearing threshold and middle ear function at the start of each session. A Teledyne Avionics Model TA-3D Acoustic Impedance Meter was used to obtain a tympanogram, a measure of middle ear function. Standard clinical procedures were observed and every attempt made to keep the standard procedures identical from session to session.

Subjects reclined on a special adjustable bed, part of standard hospital equipment, with eyes closed. Then 9mm silver disk recording electrodes were placed at the designated topographical locations on the scalp using the 10-20 International System (Jasper, 1958): the active electrode was placed at the vertex (Cz), and reference electrodes at left (A1) and right (A2) earlobes, with a ground electrode applied to the central forehead region Fpz. (see Figure 1).

Figure 1.
Electrode connection for BAER records. The larger circle represents the scalp and the letters indicate the placement of electrodes.



Two channels for each monaural presentation were monitored: monaural referenced to ipsilateral earlobe (ear to which the auditory stimulation was presented) and to contralateral earlobe (side opposite the ear to which auditory stimulation was presented). Collections for binaural stimulation used linked earlobes as reference.

Stimuli of 100 usec condensation clicks were presented at a rate of 11.1 per second, at a level of 80 dB nHL. Two separate sets of responses, n=2000, were averaged for each stimulation condition, with a filter setting of 150 to 3000 Hz with 6 dB/octave roll-off, and an averaging window of 10 msec post-stimulus onset. BAERs were processed by the Nicolet CA 2000 and all records stored on disk for offline analysis. The latency of each peak from the waveform of the second set of averaged responses was measured using a digital cursor having a resolution of 0.02 ms. Waveforms for the first set of averaged responses (n=2000), and those for the contralateral ear were used to clarify wave peaks in instances when the point of the peak was not clear. An artifact rejection feature set at 25uV peak-to-peak was used to prevent trials which were contaminated by movement (neck muscle or eye muscle) from being summed with the electrical potentials forming the BAER waveform.

Hypothesis to be tested

The following hypotheses were tested at the 0.01 alpha level; the first two hypotheses examine the BAERs across sessions (time).

1. No significant within-subject differences will be found in the stability of the BAER latencies for peak, ear or time.
2. No significant between-subject differences will be found in the stability of the BAER latencies for peak, ear or time.

The second two hypotheses address the BAER without regard to change across sessions.

3. There will be no within-subject significant difference in the stability of latency measures by peak or ear of presentation when data are collapsed across sessions.
4. There will be no between-subject significant differences in the stability of latency measures for peak or ear when data are collapsed across sessions.

Data Analysis

Data from this study are presented in the form of peak latency responses recorded in milliseconds (msec) of the first five BAER peaks for each subject for each session. Mean, standard deviation, and coefficient of stability (CS), was recorded for each subject for sessions 1-4, 5-8, and for all 8 sessions, for each ear (left, right, and binaural), and recording montage (ipsilateral, contralateral).

The obtained data were converted into CS by dividing the mean by the standard deviation; these CSs, in turn, were used to graph each peak-by-ear condition. The final observation was obtained by a direct comparison of BAER absolute latencies to previously established normative data in Picton, Stapells, & Campbell's (1981) work. The comparisons included interpeak intervals for peaks I to V for each individual averaged across eight sessions.

RESULTS

This chapter presents the findings related to hypotheses presented in the previous section. The variability measures reflect the latency of five vertex-positive peaks of the brainstem auditory evoked response (BAER) collected under a repeated-measures design. Averaged latencies of peaks I, II, III, IV, and V were calculated for 7 subjects for each of three ear conditions: left monaural, right monaural and binaual. Then averaged latencies were calculated for sessions 1-4 (A), 5-8 (B) and for all eight weekly sessions (1-8).

One data point for each subject represented the latency (msec) for each peak (5), for each ear (3), over time (A, B, and total sessions 1-8). Between-subject analysis was performed by averaging the latency in msec of each of the five peak by ear conditions, across subjects (n=7) and then across sessions (A, B, and total). Within-subject data were compiled by averaging the latency of each of the five peaks, by ear for all 8 sessions, and then across subjects (n=7).

For both between-subject and within-subject analysis the variability measures were expressed using a ratio of mean latency divided by standard deviation. This index is the reciprocal of Pearson's Coefficient of Variation, and is referred to here as the Coefficient of Stability (CS). A summary of these comparisons displaying the mean and CS for the five brainstem peaks by ear (left, right, binaural) across time (A, B and Total 8) are presented in Table I for between-subject and Table II for within-subjects.

The range of between-subject CSs for Time A (sessions 1-4) is 14 to 52 with a median CS of 23. Between-subject CSs for the second four sessions (Time B: sessions 5-8), range from 18 to 38 with a median CS of 28. Between-subjects CSs for total sessions (1-8) show a range of 16 to 37 and a median CS of 26.

Within-subject CS values show a different pattern of variability as presented in Table II. CS for Time A range from a low of 24 to a high of 100 with a median of 62. Time B shows a CS range of 41 to 100 and a median of 69. The overall range of within-subject CSs is 22 to 80 with a median of 44. It is evident that the CSs reflecting consistency of BAER responses within-subjects are greater than those between-subjects. As expected, overall, the brainstem responses in normal hearing subjects show stability across time (8 weeks).

Table I.

Between-subjects values for means and coefficient of stability.

Peak		I			II			III			IV			V		
EAR		L	R	B	L	R	B	L	R	B	L	R	B	L	R	B
Ssn																
A	X	1.66	1.65	1.67	2.67	2.73	2.78	3.73	3.77	3.77	5.04	5.13	5.16	5.67	5.63	5.67
	CS	18	14	17	19	20	27	25	30	29	20	28	52	24	23	16
B	X	1.63	1.62	1.65	2.63	2.70	2.75	3.70	3.75	3.73	4.89	5.12	5.07	5.63	5.69	5.70
	CS	18	18	22	29	22	24	33	33	31	18	38	32	29	28	28
Tot	X	1.65	1.63	1.66	2.65	2.72	2.77	3.72	3.77	3.75	4.96	5.17	5.12	5.65	5.66	5.67
	CS	18	16	19	24	21	26	28	31	30	19	33	37 4	26	26	21

Note. Comparison of actual values, mean and coefficient of stability, (CS). Values given are for between-subjects and represent the averaged mean or CS for each peak (I, II, III, IV, V) and ear [left (L), right (R), and binaural (B)], calculated over 7 subjects, and then across sessions 1-4 (A), 5-8 (B), or 1-8 (Tot).

Table II.

Within-subject values for means and coefficient of stability.

Peak		I			II			III			IV			V		
Ear		L	R	B	L	R	B	L	R	B	L	R	B	L	R	B
Sesn																
A	X	1.66	1.65	1.67	2.67	2.73	2.78	3.73	3.78	3.77	5.05	5.14	5.19	5.67	5.63	5.67
	CS	41	29	24	38	62	69	100	79	62	56	47	81	24	23	16
B	X	1.63	1.62	1.65	2.63	2.70	2.75	3.69	3.75	3.73	4.89	5.12	5.07	5.63	5.69	5.70
		41	47	41	50	46	64	71	83	88	48	74	100	29	28	28
Tot	X	1.65	1.63	1.66	2.65	2.72	2.77	3.72	3.77	3.75	4.96	5.17	5.12	5.65	5.66	5.67
		31	22	26	34	48	59	50	63	62	43	39	80	59	42	44

Note. Values given are for within-subject and represent the averaged mean or CS for each peak (I, II, III, IV, V), and ear (left, right, binaural), averaged over sessions 1-4 (A), sessions 5-8 (B), or session 1-8 (Tot) and then across subjects.

Although data presented in the above tables give an overview of the stability patterns of BAERs, a further analysis was done using a 3 Factor ANOVA: time (2 levels) X peak (5 levels) X ear condition (3 levels). The ANOVA examined the extent to which differences in performance patterns exist across different levels of these factors. Between-subjects analysis demonstrated a significant main effect for peak (F=2.07; df 4,12; p < .01) (Table III).

Differences among the CS means for ear of presentation (left, right and binaural) did not reach statistical significance (F=1.02; df 1,3; p < .37). Neither was the overall stability of individual BAER responses across sessions significantly different (F=2.07; df 2,6; p < .21) when subjects were compared to each other. The only other significant effect was a peak-by-ear interaction (PxE; p < .01); see Table III). The other two-factor interactions: time x peak (TxP; p < .23), and time x ear (TxE; p < .35), and the three-factor interaction, time x peak x ear (TxPxE; p < .31) were not significant (Table III). A post hoc multiple comparison procedure was chosen to further analyze these results. The Tukey method was selected based on its ability to make crosswise comparisons between various means. The post hoc testing failed to reveal additional details concerning contributions to the variance in peaks.

Table III.

3 way ANOVA table for main effects and interaction, betweem-subjects.

Source	DF	SS	MS	F
Time	1	187.99	187.99	1.02
Error	3	552.09	184.05	
Peak	4	2837.56	709.39	37.45*
Error	12	227.33	18.94	
Ear	2	391.69	195.85	2.07
Error	6	568.32	94.72	
T*P	4	383.33	95.83	1.65
Error	12	695.45	57.95	
T*E	2	247.87	123.93	1.27
Error	6	587.18	97.86	
P*E	8	2093.05	261.63	3.30 *
Error	24	1900.00	79.19	
T*P*E	8	916.03	114.50	1.46
Error	24	1878.01	78.25	

* $p < .01$

The same factorial analysis of variance was conducted for within-subject stability (CS) across the eight sessions for each individual (Table IV). The results indicate that there were no significant differences as a function of time (F=4.13; df 1,2; $p < .18$), peak (F=.83; df 4,8; $p < .54$) or ear (F=2.37; df 2,4; $p < .21$); neither were there significant interactions between time x peak (T x P; $p < .99$), time x ear (T x E; $p < .92$), peak x ear (P x E; $p < .29$), nor time x peak x ear (S x P x E; $p < .07$) at the .01 level of probability (Table IV). Results failed to show differences in the stability of BAER responses as a function of time, although the three way interaction within-subjects (peak x ear x time) tended toward significance.

Table IV.

3 way ANOVA table for main effects and interaction, within-subjects.

Source	DF	SS	MS	F
Time	1	6790.64	6790.63	4.13
Error	2	3286.27	1643.13	
Peak	4	5507.67	1376.92	.83
Error	8	13334.60	1666.82	
Ear	2	9811.33	4905.67	2.37
Error	4	8263.91	2065.98	
T*P	4	165.17	41.29	.07
Error	8	4408.17	551.02	
T*E	2	186.89	93.45	.08
Error	4	457.42	1144.85	
P*E	8	7740.25	967.53	1.35
Error	16	11505.25	719.08	
T*P*E	8	6643.77	830.47	2.31
Error	16	5748.65	359.29	

Note: no significant results

To further evaluate the variance in CS measures with young subjects, relative to ear condition and peak, and to compare results with those found for adults under similar conditions (Lauter & Loomis, 1986), a 2 way ANOVA, collapsed across time, was performed. Table V displays the ANOVA table for the between-subjects comparison. Evident is a highly significant effect for peak and peak x ear interaction, $p < .01$).

Analysis of variance for the CS measures within-subjects was also computed. Results demonstrated similar statistical differences for peak and peak x ear interaction. No significant differences were found for ear (Table VI).

Table V

ANOVA table for main effect and interactions (peak and ear), Between-subjects.

Source	DF	SS	MS	F
Peak	4	2837.56	709.39	15.21*
Error	28	1306.11	46.64	
Ear	2	391.70	195.85	1.95
Error	14	1403.37	100.24	
P x E	8	2093.04	261.63	3.12*
Error	56	4694.64	83.83	

*p < .01

Table VI

ANOVA table for main effect and interaction (peak and ear), within-subjects.

Source	DF	SS	MS	F
Peak	4	12854.04	3213.51	2.93*
Error	24	26351.16	1097.96	
Ear	2	2876.01	1438.00	1.96
Error	12	8796.73	733.06	
P x E	8	8751.45	1093.93	2.91*
Error	48	18028.09	375.58	

*p < .01

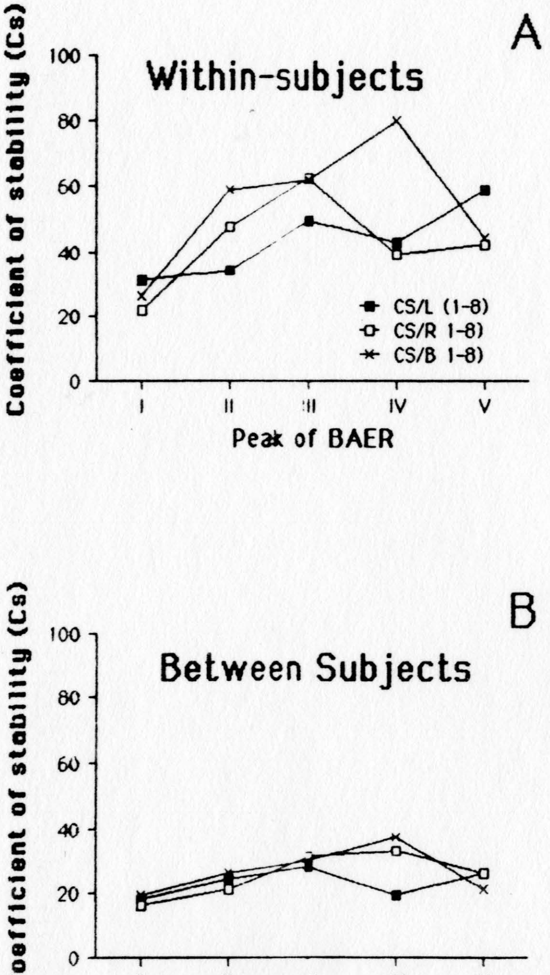
The 2 factor interaction for both between-subjects and within-subjects comparisons is graphically illustrated in Figure 2. In panel A the within-subjects CSs are plotted for each peak under each ear condition. Panel B shows the averaged between-subjects CSs for each peak under each ear condition.

As is clear in Figure 2, an overall greater stability for brainstem responses is found when individuals are compared to themselves than when they are compared to each other. The within-subject CS stability measure increases from peak I to III in each ear condition within-subject, with the CS being considerably larger for peak III than for peak I. CS profiles for between-subjects show a low stability for all ear conditions and the greatest fluctuation in stability appears in peak IV.

Figure 2

Interaction effect for peak and ear.

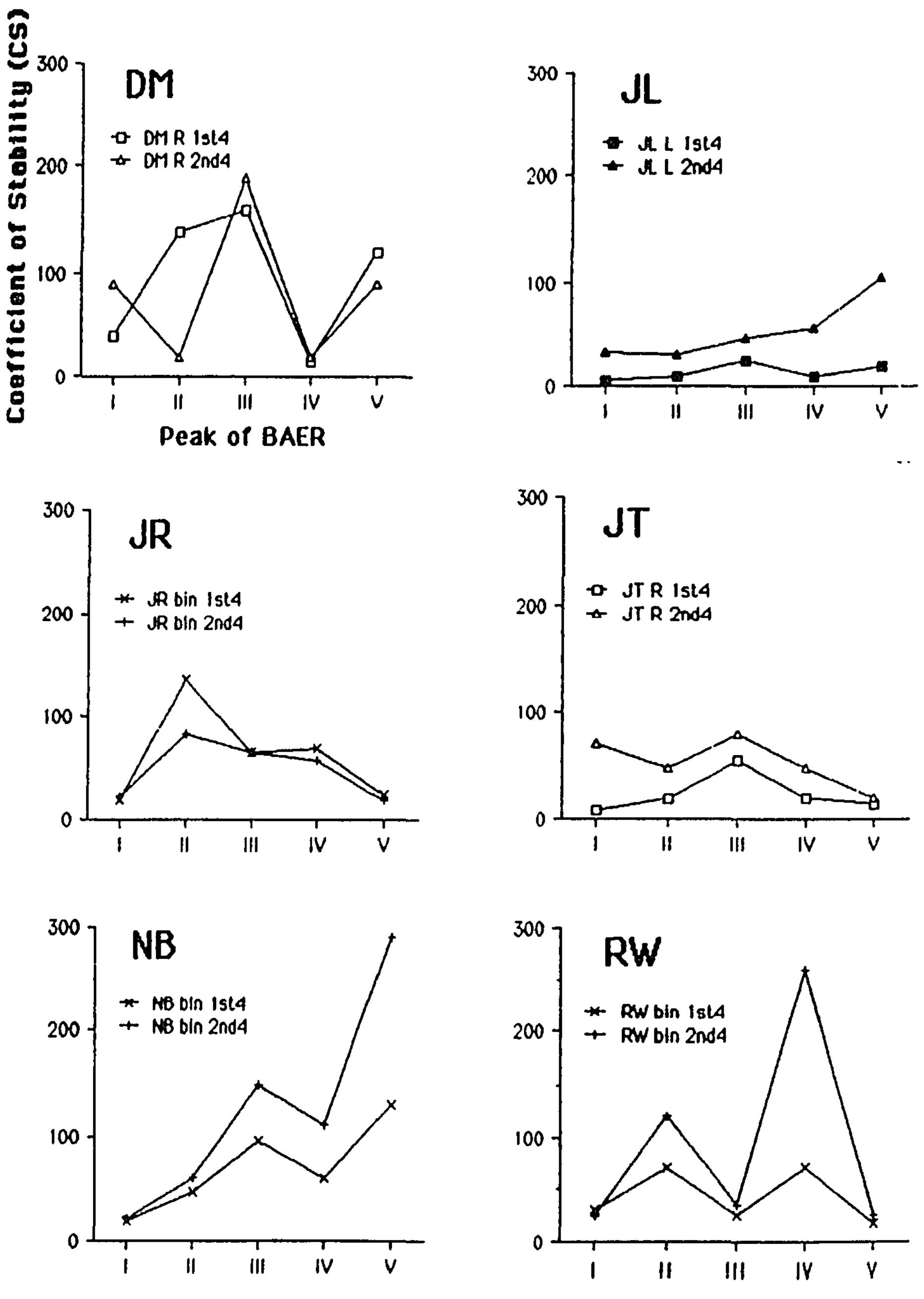
Panel A: within subjects; Panel B: between subjects.



Stability within an individual's BAER response can be further described by intra-aural pattern differences. Profiles for single subjects were developed to compare the various derived CS scores for each ear condition across time. Intra-individual differences in terms of the consistency of left, right and binaural ear responses recorded from the auditory nuclei in the brainstem were compared across time (A and B). Figure 3 shows examples of those comparisons. Individual differences existed and pattern replicability was observed.

Figure 3

Comparison of the averaged Cs over time.



Thus far the BAER was investigated utilizing a coefficient of stability measure. The absolute latency of BAER waveform peaks are often the common parameter used in BAER research, therefore a direct observation was made of these measures. BAER latency responses in this study (see Table I) fell within the average range when compared to previously established normative data (e.g., Picton, Stapells, & Campbell, 1981).

Interpeak latencies (IPL) have been used to distinguish maturational changes in auditory transmission time between wave peak I and V. The interpeak latencies in this study were compared to normative data in other studies (Maurer, Rochel, & Lowitzsch, 1984; Salamy, McKean, Pettett, & Mendelson, 1978; Picton, Stapells & Campbell, 1981). Four of the 7 subjects had IPLs for binaural ear presentation that fell outside of the published IPL ranges (Table VII).

Table 7

Mean interpeak latencies for 7 subjects ages 5-6 collected over eight sessions.

INTERPEAK LATENCIES FOR WAVEFORM PEAKS I-V

Subject	Mean Latency
1	3.70
2	4.19
3	4.20
4	4.19
5	3.57
6	3.98
7	4.14

DISCUSSION

This study investigated the stability of BAER responses over time in a small group of children with normal hearing. The study is unique in that no other published study has investigated the variability in BAER latencies of young subjects over time. The intent of this research was to look specifically at individual differences in BAER responses in young children and, secondly, to compare the stability measures within-subjects to that between-subjects.

Although much of the early description of the BAER generated belief that auditory far-field potentials are stereotypical series of waveforms connected in time, clinical experience over the past decade has shown sufficient variability in responses among normal subjects to warrant studying a large series of normal records prior to using this technique in clinical evaluations. Factors influencing the normal BAER lead to small but significant differences in wave latency which can confuse BAER interpretation. Non-pathological factors can have small but cumulative consequences across variables and lead to interpretative errors. There is a need to establish baseline measurements concerning patterns of individual variability for parameters such as latency, amplitude, and interpeak intervals.

As reviewed in this paper, researchers have reported on normal variability in groups of subjects or differences between selected groups. Few studies have analyzed individual variability over time, and no published studies were found that measured stability of BAER responses in young children over time. The following discussion concerns the stability of single subject BAER responses in a repeated-measures design.

BAER latencies reflecting activity of the brainstem auditory nuclei were collected from each of 7 subjects in a series of 8 sessions per subject. These latencies will be discussed in two ways. First the results from the ANOVA are discussed, followed by a discussion on direct comparisons between absolute latencies and interpeak latencies with previously published normative data.

Coefficient of stability (CS) measures derived from the BAER latencies were used to compare stability measures between and within-subjects. The calculated CSs demonstrated an overall tendency toward increased stability. Of the 30 calculated CS measures (right, left, binaural ear presentations, 5 peaks, two groups) 80% showed an increase in the stability measure over time.

Results from the statistical analysis of the variability for peak (5 levels), ear (3 levels) and time (2 levels) showed a significant difference in stability as a function of peak but not ear or session when subjects were compared to each other. The main effect for peak, further qualified by a significant peak by ear interaction, suggests that the stability in peak latency is different in relation to the ear(s) stimulated.

In contrast, within-subject analysis (averaged CS measured for eight sessions and across 7 subjects) demonstrated no significant differences for peak, ear, or session (1st 4 weeks compared to second 4 weeks) or any interactions. The difference found for the between-subject and within-subject comparisons was unexpected. It is not surprising to demonstrate that individuals are more like themselves than they are like each other, however an intra-individual difference between ears was anticipated based on previous studies. For example, Obrzut et al. (1987) found significant inter-ear differences in the averaged latency of peak I but not for peaks III and V in a group of normal hearing adults. Piggott & Anderson (1983) demonstrated individual differences between binaural and monaural records for latency measures of wave peak III in their experimental group (7-13 years of age). At present it is not clear what accounts for the difference in studies. It is speculated that procedures, methodology and sample differences may be an explanation.

This study is unique in that it investigated the stability of BAER latencies in young subjects over time. Lauter and Loomis (1986) reported a similar analysis of BAERs in adults, testing two factors, peak and ear. They observed significant effects for peak but not for ear when adult subjects were compared to each other; within-subjects comparisons indicated significant differences in stability measures as a function of both peak and ear of presentation.

Results from the current study based on BAER responses collapsed over time, in a considerably younger age group, found significant differences for both peak, and peak-by-ear interaction, within-subjects as well as when subjects were compared to each other. This shows that the stability of peak latencies is not constant across left, right and binaural ear presentations in this age group.

Consistent with the Lauter and Loomis (1986) study, a main effect for peak was found between and within subjects and no effect for ear was found between-subjects. Different from their study, this research indicates that the significant difference in latency variability for the different peaks interacts with differences due to the ear stimulated, although no main effect for ear was found. It is possible that the differences between studies may reflect differences in the age of the samples studied.

The interaction effects found for between-subjects suggests that when individuals are compared to each other the greatest variability between ear conditions lies at peak IV with the left ear demonstrating the lowest stability. Within-subjects analysis suggests greater overall stability for each ear condition and a similarity in the CS pattern for the first 3 peaks with greater variability among ear conditions in the latter 2 peak components. The results present a valid description of the peak by ear interaction for this sample of children; however, more research is needed to clarify whether such differences are normal physiological differences or whether they represent artifacts. This study is a step in that direction.

Absolute latency is the parameter most often measured in BAER studies. Interpeak latencies (IPLs: I-III, III-V, I-V) are also routinely considered important in studies utilizing BAERs (Rosenhall, Bjorkman, Pedersen & Kall, 1985). Rosenhamer, Lindstrom, and Lundborg (1980) demonstrated significant latency differences between young and old females but not for young and old males. Jerger and Hall (1980) found that peak I latency did not change with age, yet there was an 0.2 msec difference in Peak V with 25 to 55 year old subjects, thus indicating an age associated delay in the I-V IPL. In contrast, no age related change in IPL was found by Rosenhall et al. (1985).

The present results indicate an increase in the I-V IPL of 0.1 msec greater than the normative range established by Picton, Stables and Campbell (1981) in 4 of the 7 subjects tested. When the I-V IPL was compared to the normative data established by Mauer and Lowitzsh (1984) no differences were noted. One possible explanation for this could be that the study included more pediatric subjects with its normalization procedures (the number of subjects for age groups used were not provided in the study). Another possibility for this difference could be differences in procedures (e.g., variations in stimulus factors).

Note that although children are often evaluated against adult norms, the mean (8 observations) IPL latencies in 4 of the currently tested subjects are closer to the normative range established for 3 year olds than for those established for adults in Salamy, McKean, Pettett & Mendelson’s (1978) work. Such differences in I-V latency suggest the need for further investigation of normal variability based on age of the population to be studied. The consensus of several studies (Jacobson, Morehouse & Johnson, 1982; Schulman-Galambos & Galambos, 1975) is that immaturity in the auditory system is reflected in the BAER by IPL delays of the three primary components, I, III, V. Schwartz and Berry (1985) indicate that collection of age relevant normative data commensurate with the population to be studied is mandatory for appropriate interpretation of the BAER in relation to auditory neurologic integrity of infants. Although they are concerned with infants, similar requirements seem to be warranted for other pediatric age groups as well.

Interpretation of abnormal BAERs requires a full knowledge of what is normal (Picton, 1986). Stability of BAER responses in a small group of average children was investigated here. The results suggest the existence of significant individual differences as a function of peak as well as in terms of an interplay between peak and ear. The mean BAER latencies found in this sample are comparable to the range cited for normal BAER latencies; however, maturational differences are implicated in that the IPLs (considered as reflecting the conduction time through the brainstem) extend beyond the adult range expressed in previously published norms.

Salamy et al.'s (1978) study, concerned with the stability of BAER responses, suggested a progressive increase in stability with age. This conclusion is supported by the results found here, in that the median CS and CS range for children appears to be lower than the median CS and CS range found for adults (Lauter and Loomis, 1986).

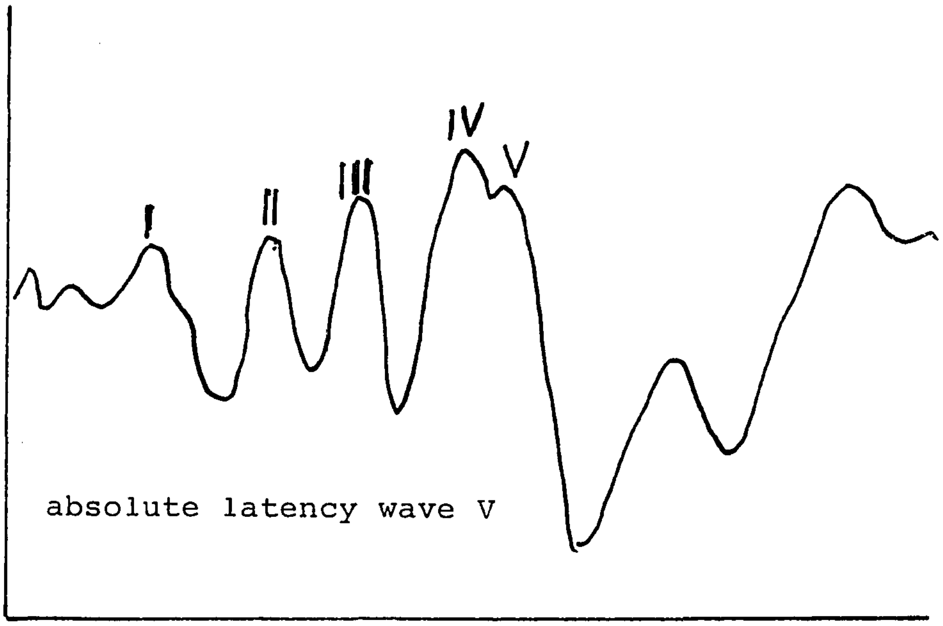
Results in this study corroborate those found with adults (Lauter & Loomis, 1986) in that there are individual differences in the stability of BAERs. The reliability of the data can only be considered suggestive in view of the small number of subjects, though the present results are encouraging for future research concerning the significant interaction effect of peak and ear. Overall, the sample of young subjects investigated here produced more variable BAER responses than Lauter and Loomis' (1986) adults, yet 80% of CSs for this study increased over time. Furthermore some within-subject replicability in the CS profiles was demonstrated. The similarity in CS profiles by ear and the differences noticed across ear conditions present implications for future research concerning laterality and physiological development of the auditory nervous system.

Results such as direct comparison of the calculated IPLs in this study to previously established normative data and the trend in central tendency measures to increase across the 2 age groups (children compared to adult) have implications for future research concerning developmental issues regarding the auditory nervous system. Applications of this research could be to define normative data specific to the age group investigated or perhaps to provide more definitive information for future classification of auditory processing disorders.

Results support the need for future research to discern subtleties of individual differences and clarification of differences reflected in CS profiles for ear of presentation. The use of other statistical techniques for the analysis of these individual variances in BAERs is currently being investigated. Techniques such as profile analysis, a generalizability method and a technique used by Berlin et al. (1984) to investigate asymmetries are possible approaches which may help to describe the subtle individual differences suggested by the results of this study.

The BAER appears to be a promising research tool. Applications such as charting development of the central auditory system could be used as a baseline for clinical interpretations. Continued research with individual differences in the BAER over time could reveal pattern responses that could be used in early identification of young children at risk for auditory processing and language development disorders. Research could extend toward efforts in categorization of children with learning difficulties.

APPENDIX



An example of normal BAER waveform. The roman numerals represent a numbering system for each of the 5 peaks (Jewett, et al., 1970).

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